1) What are the aims & Objectives of well logging? Add a note on borehole geophysics.

Aims & Objectives of Well Logging. Unit - 1

→ Bore hole physical data recorded against depth to evaluate the characteristics of subsurface formations traversed by a logging tool in wellbore.

→ First Well Log - Measurement of Electrical resistivity - Marcel, Conrad & Schlumberger - 1927. (France)

"Electrical Coring"

→ Well Log - Log is record of events during an Incident.

→ Record of observations made during Various sections / sessions of a well.

→ Also Called "wireline log" - lowered on Cable (wireline) into well. Measurments transmitted to software up in lab. This recorded information in paper / film is a well log.

→ Different log data taken - each constitutes different property of rocks penetrated by well.

→ Wireline log after drilling / Drilling log during drilling (drilling rate, mud loss, torque) / Mud log (Mud salinity, pH, Mud weight).

Importance of well log:..

→ Geology: Study of rocks making up Earth's crust.

→ Sedimentology: Hydrocarbon-forming Sedimentary environments, Detailed study of Composition, texture, structure of rocks, color of constituents, identification of any traces of organisms.

→ Geological findings: Identify phy. che, bio condition prevelant for deposition / transformation the formation has undergone. / Organization of different strata into series & deformation by faulting, folding.

→ Samples cut from rock outcrops. Rock samples from Cores (core-barel cutting), not practised due to economic reasons. Sidewall cores (Core gun) from wall of a hole after drilling present few difficulties → don't provide continuous information. Cuttings (rock samples flushing to surface) are source of subsurface sampling. As this undergoes many process like mixing, leaching, contamination & when mud circulation is lost, this process is limited. These are reasons for insufficient Data.

That is the reason to go for indirect ie welllogs

Well logs show porosity, lithology, hydrocarbon formation, rock properties, saturation of reservoirs rocks, depth correlations, and many geological & petrophysical properties of the strata. Also tells us about fluids in the rock.

A log data is an objective translation of state of things that one can't change (in a paper) of a scientific fact.

Log data —SIGNATURE OF A ROCK→
- → PHYSICAL
- → CHEMICAL
- → BIOLOGICAL
- → GEOGRAPHICAL
- → CLIMATIC

} Conditions during deposition & its evolution

i) Significant change in any geological characterstic is detected by atleast one parameter through one/more logs.

ii) Any change in log response indicates a change in geological parameter.

→ Well logging plays a main role in development of hydrocarbon reservoir from seismic survey (locating a well) & Production Testing.

→ Wirelire log is only limited to formation evaluation & Complection evaluation.

Borehole Conditions / Borehole geophysics:

Borehole conditions affecting log measurements are

1) hole size 2) Drilling 3) Mud Cake 4) Mud filterat

→ When a well is drilled the borehole is filled with drilling mud / fluid. Rock pieces comesout with mud & hole is drilled. Pressure of mud is maintained higher than the formation pressure so that the oil / gas doesn't comesout due to overpressure on them.

→ If rock is permeable, then the mud tries to enter into rock, rock pores act as filter so that the water gets inside the pores & it invades the formation water inside rock.

→ The mud forms a mud cake and stops the invasion overtime. The part of rock which is invaded by any fluid is called "the invaded zone, those that are not disturbed or invaded (due to non-permeable rock) is called" uninvaded zone or Virgin zone".

→ Resistivity of these zones from centre to outside of wellbore are Rm, Rmc, Rxo & Rt

Significance of Resistivity Data:

→ To estimate effect of borehole mud & mud filterate invasion.

→ To resolve true formation resistivity (Rt)

→ Determine extent of invasion

→ Finding out resistivity @ different diameters

Resistivity @ Various places:

→ Drilling mud Resistivity (Rm) on drilling mud

→ Mudcake resistivity (Rmc), effect of drilling mud on permeable formations

→ Two components of invaded Zone

fully flushed / transition.

27

→ Fully flushed by mud filterate; partially flushed - "transition & other is invaded.

→ Mostly transition Zone is neglected & diameter of invasion is measured to edge of flushed Zone.

→ Resistivity of Mud filterate (Rmf); residual hydrocarbon resistivity measured as (R_{xo}), associated water saturation is S_{xo}.

→ Resistivity of undisturbed formation (R_t); Interstitial water Resistivity (R_w) & water saturation

→ Flushed Zones are important as it affects the readings of certain logging tools because it form a reservoir mudfilterate & has to be recovered before the formation fluids are recovered.

2. What are the formation parameters? Explain how it is useful in analysis of well logging data?

Porosity:

→ Ratio of Void space in rock to bulk volume

→ Measure of internal space to contain fluids.

→ Solution type porosity is found in carbonate rock, porosity changes depending on any chemical r.x.n. taking place after deposition.

→ Porosity also develops in form of fractures induced by stresses of tectonic movements.

Porous rock — Grain Volume (V_g) / Pore Volume (V_p)

$$V_b \rightarrow V_g + V_p$$

$$\phi = \frac{V_p}{V_B} = \frac{V_b - V_g}{V_b} = \frac{V_p}{V_G + V_p}$$

→ Value of Porosity depends on porosity measuring device & knowledge of two/three volume fractions.

→ Vary widely from point to point

→ Presence of vugs & fractures can change permeability.

→ Porosity – Primary, Secondary, Dual. But effective porosity counts for reservoir evaluation.

Primary Porosity:

→ Spaces b/w fragments of solid, deposited as sediment are primary porosity.

→ As the compaction/cementation increase, the sediment turns to rock with reduction in primary porosity.

Secondary Porosity

→ As the time goes, chemical composition of the rock changes, with which the precipitation happens between the rock & the cement. This action creates secondary porosity.

→ Secondary porosity is relative to the physical / chemical properties of the system.

Total Porosity:

→ Combination of primary porosity & secondary porosity.

→ Ranges from 3% to 35%

Effective Porosity: (only Considered)

→ Process subsequent to sedimentation, cementation, recrystallization, solution, weathering & fracturing can modify proportion & distribution of Void space.

Saturation:

→ Volume of fluid to the Volume of pores in which fluid is contained is called fluid/gas saturation.

$S_w + S_o + S_g = 100\%$ (Any Combination)

Ac. to wettability, reservoirs mostly

contain a thin water film coating the rock surface around the parameter of pores

Wettability :

A liquid when contacts with solid, contacts with a minimum surface area. The angle θ measured through liquid from its surface area is called contact angle.

Wet $\theta < 70°$

Intermediate wet $\theta = 70°$ to $110°$

Non Wetting $\theta > 110°$

$\theta = 0°$ for completing wet

$\theta = 180°$ for completely non-wet.

Water wet rock - affinity b/w rock & water is higher than rock & oil. and so vice versa

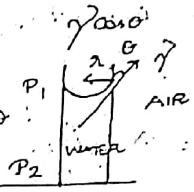
If oil saturation is 25%, then oil will become discontinuous phase and it becomes isolated globules surrounded by water. During primary production, pressure depletion & water injection will not work, whereas we require to inject chemical / gas will reduce mobilizing oil left behind during primary production.

Surface Tension:

Imbalance between the gas & liquid molecules results in the energy requirement to increase the surface area to pull the fluid out of bulk of solution. This is called Surface tension.

Capillary Pressure:

$$\Delta P = P_1 - P_2 = \frac{2\gamma \cos\theta}{r}$$



→ Pressure difference b/w interfacial layers across a curved surface is capillary pressure.

→ Causes the rise of wetting fluid in tubes of radius of tube. (internal cohesion)

→ In case of two different fluids, $P_c = \Delta P = (\rho_w - \rho_a) gh$

$$h = \frac{P_c}{(\rho_w - \rho_a) g} = \frac{2\gamma \cos\theta_{a/w}}{r g (\rho_w - \rho_a)}$$ ($\theta_{a/w}$ or $\theta_{o/w}$)

Homogeneous rock - pore size - r

Permeability:

Ability of porous system to allow fluids to flow through.

Darcy Eqn. (Laminar)

$\frac{\Delta P}{L}$. Head loss per unit l...

$$k = \frac{Q \cdot \mu \cdot L}{\Delta P A}$$

Absolute permeability → Rock property is independent of fluid that is flowing through.

$1D = 0.9869 \times 10^{-12} m^2$

Also,

$$k = a\left(\phi_e^{b} / S_w^{c}\right)$$

↳ Water saturation

Effective porosity

a, b, c → Constants

Directional Effects

→ Reservoir permeability is a directional property.

→ cross stratification

→ Cross bedding, Bioturbation, cementation, grain size sorting & packing Varies permeability

→ Horizontal permeability is measured parallel to bedding.

→ Vertical is lower than horizontal.

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ϕ_e → Effective porosity

a, b, c → Constants

Directional Effects:

→ Reservoir permeability is a directional property.

→ Cross bedding, Bioturbation, Cementation, grain size sorting & packing varies permeability
(→ cross stratification)

→ Horizontal permeability is measured parallel to bedding.

→ Vertical is lower than horizontal.

High k_v in clean, coarse sand due to jointing or vertical jointing. May be filled with clay, silt, minerals...

Absolute Permeability:

Measured when a pore space is 100% saturated with a fluid.

Effective Permeability.

Measure of permeability of flowing phase which doesn't saturate 100% of rock.

Eg: Oil phase in water.

1) $P_E < P_A$

2) $P_E \propto$ Saturation of rock. (simple rock structure)

3) $P_E \propto$ Capillary pressure (Complex rock) + Wetting + Saturation history.

Relative permeability.

$$k_{rw} = \frac{k_w}{k}; \quad k_{ro} = \frac{k_o}{k}; \quad k_{rg} = \frac{k_g}{k}$$

In reservoir, the fluid settles under 2 factors: Gravity & Interfacial, Surface Tension.

Electrical Resistivity of rocks:

→ Igneous, metamorphic, dry sedimentary rocks are poor conductors of electricity & have high resistivity.

→ Sedimentary rocks have pores & pores are filled with conductive water.

→ Resistivity is used to detect presence of oil & gas.

3. Explain the various physical properties of reservoir rock

→ It is a fairly stable mineral (not affected by changes in pressure, Temp, acidity of pore fluids.

→ Sandstone reservoir are formed after sand grains being transported over long distance & deposited in a deposital environment.

→ Carbonate rocks are formed in-situ at formation. Unlike Sandstone reservoir, these are susceptible to changes by process of diagenesis.

→ Reservoir rock must have sufficient thickness, Areal Extent & pore space to contain high content of hydrocarbons to be commercially producing when reservoir is penetrated by well.

→ Hydrocarbon first fills up the pores in sandstone by replacing the air space which is filled with water.

→ An effective reservoir will have communication b/w pores to be migrative & to move towards borewell once a well is drilled.

→ Reservoir which some porosity & low permeability is considered tight.

Traps

-> As the hydrocarbons have lower density than water, if no mechanism stops, they automatic seep to surface and gets trapped.

-> Anticline traps are a result of ductile crustal deformation.

-> Fault traps are a result of little crustal deformation.

-> Stratigraphic traps are where impermeable strata seals the reservoir.

-> Most of traps are found in fault bound anticline traps, called "Combination traps".

-> Inspite of all favourable condition, there may not be a accumulation can lie due to timing of event.

-> As the hydrocarbon has to go thru stages of Maturation, Migration and the reservoir must have a seal thruout geologic time. If a leak occured, then there will be a very less amount of hydrocarbons or bacteria might have biograded the light fractions.

On Probablity, every third or tenth well is only successful.

Nomenclature of a trap:

→ Highest point of trap is called crest / culmination

→ Lowest point is spill point.

→ Trap may / may not be full spill point.

→ Horizontal plane through spill point is spill plane.

→ Vertical distance from high point @ crest to low point @ spill point is closure.

→ Productive reservoir is pay.

→ Gross vertical interval is gross pay.

Not all gross pay of a reservoir is productive.

→ Net pay is possibly productive reservoir.

→ Total thickness of reservoir as per well log – H.

→ Gross pay thickness, thickness of hydrocarbon bearing portion of reservoir as determined by log. While this thickness contains shale breaks which is not productive & to be discounted to determine net pay.

$$\text{Net pay} : h = \sum_{i=1}^{6} h_i$$

$$\text{Net to gross (NTG)} : \frac{h}{h_0} = \frac{\sum_{i=1}^{6} h_i}{h_0}$$

→ OWC, Oil Water Contact is deepest level of producible oil within reservoir.

4) Enumerate on the formation evaluation of hydrocarbons?

Formation Evaluation

i) Identify / Infer presence of hydrocarbon in formation traversed by wellbore.

ii) Identification of the depth of formation Containing Hydrocarbon.

iii) Calculating the hydrocarbon Content:

i) Fractional Volume available for hydrocarbon in formation. Porosity, & Quantity are significant.

ii) Quantify the hydrocarbon fraction of fluids in the rock Matrix.

iii) Areal extent of bed / geological body Containing hydrocarbon.

iv) How Producible the Hydrocarbons. Depends on permeability, Viscosity.

v) No. of Measurement Devices & Interpretation techniques are developed that shows values of porosity hydrocarbon saturation, as a fn. of depth.

These Measurement says about.

i) Location of oil bearing & gas bearing formation

ii) Estimate of their producability

iii) Assessment of quantity of hydrocarbon in place in reservoir.

Completion Evaluation

Group of Measurements concerning cement quality pipe & tubing corrosion, pressure Measurement. Some Applications of borewell measurements well logs is as follows.

Primary { i) Estimating recoverable hydrocarbons.
ii) Estimating hydrocarbons in place.
iii) Rock typing.
iv) Abnormal pressure detection
v) Evaluating Rock stress.
vi) Locating Reservoir fluid Contacts
vii) Fracture Detection
viii) Identifying Geological Environments.

$N = 7758\ Ah\phi\ So/Bo$

$G = 43560\ Ah\phi\ Sg/Bg$

N, Initial oil in place, stb.

G, Initial gas in place, scf.

ϕ, Effective porosity.

So, Sg - Initial oil/gas Saturation.

Bo, Bg - Initial oil/gas formation factor.

A - Area of Drainage, acres.

h - Interval thickness.

6) What is a Reservoir formation? List the types of reservoir formation and their properties.

Reservoir formation:

A petroleum reservoir is a oil/gas reservoirs as a subsurface pool of hydrocarbons contained in porous/fractured rock formation. Types of Reservoirs: i) clastic/silicate ii) Carbonate

i) Clastic / Silicate reservoirs.

→ Formed by weathering & transport of material

→ Mechanical weathering induced when a rock is exposed to severe temperature change or freezing of water in pores & cracks.

→ Chemical weathering caused due to substances contained in surface water.

→ Weathering results in breaking of rock into small components & then transported by agents like water, wind, ice.

→ Transport energy decides size, shape & degree of sorting of grains.

→ Sorting important parameter for porosity.

Carbonate rocks

→ Not Transported but found at location of origin (in - situ).

→ In process of Diagenesis:

Depositional Environment:

→ Weathering & Transportation followed by Sedimentation.

→ Depositional environment defined as area with a typical set of physical, chemical & biological process result in a specific type of rock. Also with geomorphic Variables.

→ Controls porosity, peremeability, net to gross ratios, extent & lateral Variability of reservoir properties, Inturn affects production, recovery & accumulation.

Characteristics of selected Environment:

→ Core & wireline logs are important in detailed environmental analysis, specially Gamma ray response

→ GR captures change in energy during deposition, measures level of natural gamma ray activity in rock formation.

- ... ↑GR ... sandstone ↓GR

Exponent 'm' is called cementation exponent, which varies mainly with degree of consolidation of rock.

a - 0.35 to 4.78

m - 1.14 to 2.52

Formation Resistivity factor & Porosity relationship from lab Experiments:

1. Representative core samples are cleaned to remove hydrocarbons.

2. Core samples are fully saturated with synthetic brine of known resistivity R_w. (Brine similar to formation water)

3. Electric resistance r_o is measured when samples are saturated as such.

4. Then F is plotted against ϕ on log - log sheet

$$\log F = \log a - m \log \phi$$

a - intercept.

[- m] - Slope.

Most Generalized relationship b.w. F & ϕ is given by Humble's equation.   totally => 22 pages

$$F = 0.62/\phi^{2.15}$$

Humble's eq. for Sandstone.

$$F = 0.81/\phi^{2}$$

Archie's law relates in-situ electrical conductivity of sedimentary rock to porosity & brine saturation

6) Describe Archie's law and its application in well logging.

Formation resistivity greatly depends on porosity & tortuosity factors.

↳ (Impossible to measure)

Studies were completed considering various porous media models such as sphere packs, bundle of tubes for studying the relationship b/w F & ϕ, but they had oversimplification of complex system.

<u>Archie's equation:</u>

$$F = \phi^{-m}$$

Another eqn ⟹ $F = a\phi^{-m}$

a - empirical Constant

m - Cementation Constant

Here F value largely depends on a & m

Value of a & m vary with pore geometry.